Germanium Doped Glass Capsules via Glow Discharge Plasma

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Ge-doped glass capsules were important for NIF Double Shell Energy Transfer Experiments

- Ge doping for shell contrast during implosion
- D2 diffusion fillable
- Thick wall to meet mass requirements ($m_r/m_{is+\ell} \sim 1$)

* Elizabeth Merrit et al, "Experimental study of energy transfer in double shell implosions" (accepted for publication in Physics of Plasmas 2019).
Partially densified, thick-walled, undoped glass capsules were made for the initial double-shell experiment in 2017. This next phase required:

- fully densified Ge doped glass capsules
- wall thickness to a $>35\mu m$ in thickness
- very high burst/buckle strength ($>50$ atm)
- very long DD HL at room temperature
- method to DD fill GDP coated, Ge doped glass

Bottom line…. We succeeded! Both the ablator and the inner shell trajectories observed for the first time.
Ge doped glass is made using the SiGDP to glass process.

1. PAMS
2. Si-GDP/PAMS (heat in N₂)
3. Si-GDP (pyrolyze in air)

Si-doped GDP

1. (GeSi)-doped GDP
2. (GeSi)-GDP (heat in N₂)
3. (GeSi)O₂ (pyrolyze in air)
Early Ge doped glass proof-of-principle experiment looked promising

GeSi GDP

5% Si
1% Ge
Remainder CHO

GeSiO₂ (530°C)

28% Si
6% Ge
66% O

Partial conversion

Patch areas higher in Ge content by EDXS

GeSiO₂ (960°C)

28% Si
6% Ge
66% O

Full densification
Decreasing Ge content to 1.4 at% produced high quality capsules at full densification.

GeSiO$_2$ shell

Wall-mapper wall uniformity

Total $\Delta$ wall = 0.04 $\mu$m

Increasing wall uniformity with decreasing Ge content
Next up – increase GeSiO$_2$ wall thickness to $>35\mu m$ using information from LANL Double-Shell experiments* in 2017...

Hemi shell post PAMS pyro

Interfaces generated at Si-GDP coating breakpoints

No Ge dopant in 2017 experiment

Interfaces in SiGDP wall cross-section suggest breakpoints during coating increase likelihood for failure during pyrolysis

* Progress Toward Fabrication of Machined Metal Shells for the First Double-Shell Implosions at NIF- Tana Cardenas et al., FST (2018)
No “breakpoint” SiGDP run had the desired result

~1mm x 70μm SiGDP capsule

Conversion in air
(not fully densified)

~700μm x 36μm glass capsule

Full densification not attempted in time for 2017 experiment

Majority (>50%) survived PAMS pyro intact

d = 1.84g/cc (2.20g/cc)

530 C
No-breakpoint run for GeSiGDP went very well also
>50% yield after conversion to glass

Capsule after conversion to full density GeSiO$_2$ glass

~0.690mm x 43um

$d = 2.26$ g/cc; at% Ge = 1.4
Ge-Glass capsules properties were tested and found to be suitable for the Energy Transfer experiments:

**Very Strong**
- He tested
  - Buckle Strength > 100atm
  - Burst Strength > 60atm

**Appropriate size**
- ~ 700 μm OD
- > 35 μm wall
  - Glass OD (μm) ~ 690 μm
  - Wall thickness (μm) = 43 μm

**Very long DD HL but still fillable by permeation**
  - He HL = 19.6 hrs at 20°C
  - DD HL ~ 12,700 hrs (530 days)
  - ~ 20 hrs at 260°C

**Sufficient [Ge]**
- > 1%
  - [Ge] = 1.4 at% (0.11 g/cc Ge)
  - Density = 2.26 g/cc
Based on DD HL results capsules were filled with DD at high temperature prior to CH overcoat

DD HL much to long at low temperature to fill after CH overcoat (~12,700 hrs)

~72 hrs of coating time needed for CH overcoat; calculated loss of DD is minor for 72 hrs at 80°C (<5%)

By Interferometry:
Pre CH DD fill pressure = 62+/- 5 atm
Post CH DD fill pressure = 61+/- 5 atm

Final Ge-glass capsule after DD fill and CH overcoat
Glass shell research for future experiments continues - a trial to make a pure GeO$_2$ capsule shows promise.

- 1.05mm x 8µm (~35% shrinkage)
- d = 3.2 g/cc
- He HL < 1min

~6.3at% Ge-GDP by XRF
Post-PAMS removal
High Z (Pb) doped glass has been of interest in the past - Tin (Sn) doped glass capsules look very promising.

SnSi doped GDP Post PAMS removal

~1.6mm x 10.5μm

Sn doped glass capsule

~1.05mm x 7μm

Note: Pb doping was considered but the precursor is not readily available
Summary – Ge doped capsules for ET expts achieved; Tin doping and pure GeO$_2$ possible new additions

First observation of the inner shell trajectory in Double-shell Energy Transfer experiments
Elizabeth Merrit et al, "Experimental study of energy transfer in double shell implosions“ (accepted for publication in Physics of Plasmas 2019).

Nearly pure(?) GeO$_2$ capsules show promise

Tin (Sn) doped GDP capsules made for first time

Tin doped glass capsules made for first time